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Aurora of October 22/23, 1958, at Rapid City, South Dakota

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During the night of October 22/23, 1958, auroral activity at Rapid City, South Dakota, included (a) a visible aurora in the northern part of the sky and; (b) a "monochromatic" (6300 A) arc through the zenith with an azimuth 12° from east-west (geomagnetic). The intensity changes of the arc were independent of the changes in the visible aurora. It moved slowly southward during the night corresponding to a linear speed of about 8 meters per second if its height is 300 kilometers. It is suggested that it is a member of a family of monochromatic arcs which have until recently escaped detection because their red color makes them invisible even though intrinsically intense.

1. Introduction

In an earlier paper [1] [1] we described a "monochromatic" (6300 A) arc at Fritz Peak.[2] It was detached from and apparently independent of a visible aurora to the north.

According to Barbier [2] who has made a systematic study of 6300 A auroras at Haute Provence, they occur during about 10 percent of the time either as a general enhancement near the northern (geomagnetic) horizon or as arcs with maxima in the eastern and western parts of the sky. In searching our records at both Fritz Peak and Rapid City, we find, in agreement with Barbier, that they are not infrequent. In this paper, we describe an aurora at Rapid City (longitude 103°18′50″ W; latitude 44°01′ N; geomagnetic latitude 53° N) on October 22/23, 1958, which had a well-defined 6300 A arc near its southern edge.

2. Observational Material

During the night of October 22/23, 1958, the Rapid City photometer was making systematic sky surveys in the three colors—5577, 6300, and 5893 A. The surveys were in the form of zenith observations plus almucantar sweeps at zenith distances of 80°, 75°, 70°, 60°, and 40°. The complete cycle for the three colors required 15 min. The spectral discrimination was by means of a birefringent filter [3]

In figure 1 (left) is shown an example of a set of the original records. One of the striking features is the existence of sharp maxima or spikes on the 6300 A records near the east and west points of each of the sweeps, which are absent from the 5577 A records.[3] When an isophote map is made of all the observations (right side of fig. 1) the spikes are seen to define a 6300 A arc extending across the sky in a general east-west direction. For both colors, there is activity near the northern horizon which developed into a bright aurora during the night.

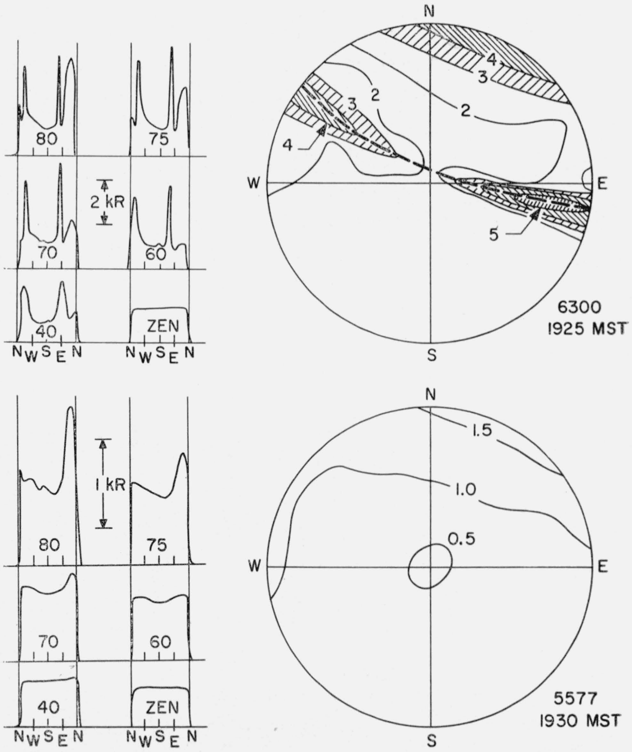

FIGURE 1. *The original records (left) for 6300 A and 5577 A at Rapid City for 1925 and 1930 m.s.t. on the night of October 22, 1958.*

Isophote maps of the sky (right) based on the original records. In drawing the isophote maps a height of 100 km was assumed for 5577 A; of 300 km for 6300 A. The unit of intensity is the kilorayleigh.

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[1] Figures in brackets indicate the literature references at the end of this paper.

[2] In this paper the word "monochromatic" is used to indicate that the 6300 A radiation is predominant over the 5577 A.

[3] It is estimated that if 5577 A spikes as weak as 100 R were present, they would be detectable.

3. Evolution of the 6300 A Arc

In figure 2 a pair of isophote maps shows a comparison of 5577 and 6300 A over the sky later in the night when the visible aurora was well developed in the northern part of the sky. The 6300 A arc is seen to have maintained its identity and discreteness independent of the visible aurora.

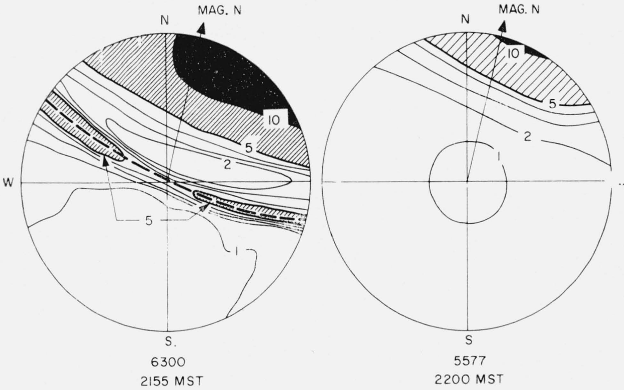

FIGURE 2. *Isophote maps for 6300 A and 5577 A for 2155 and 2200 m.s.t. after the development of an aurora over the northern part of the sky.*

To illustrate the independence of the arc, we show in figure 3 the time variations of 6300 A intensity; (a) in the extreme north-northeast for the visible aurora and; (b) for the 75° E and W spikes of the arc. It is seen that the arc intensity seems unrelated to that of the northern aurora going steadily down, as the northern aurora goes through strong variations, often as much as 10 times the brightness of the arc.

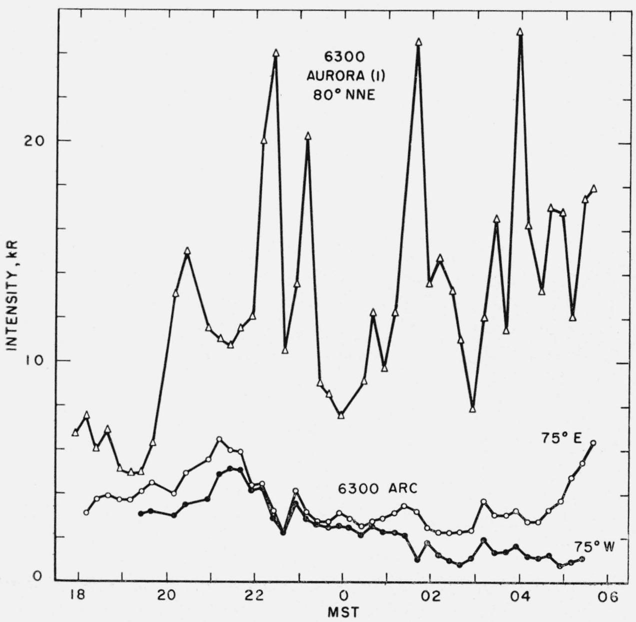

FIGURE 3. *Comparison of 6300 A time variations in two parts of the sky—at 80° zenith distance in the N-NE and the spike in the eastern and western parts of the sky at z=75°.*

In figure 4 we show the position of the 6300 A arc for four different times during the night. It moves steadily southward, as shown also in figure 5. From figure 5 we deduce a mean speed of 8 m/sec for an assumed height of 300 km. This compares with 6 m/sec for the similar arc of September 29/30, 1957, at Fritz Peak [1]; 58 m/sec for the 6300 A front at Sacramento Peak on February 10/11, 1958 (Manring and Pettit [4]); and 100 m/sec for 5577 A airglow cells [5].

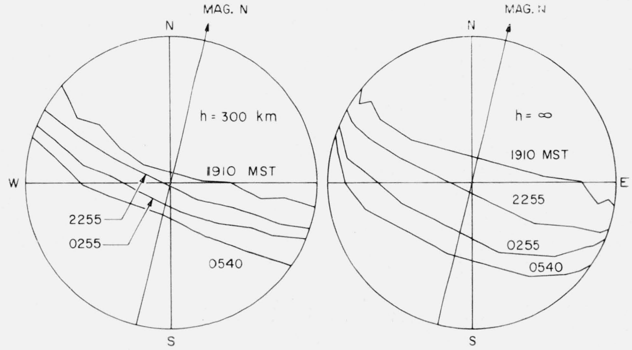

FIGURE 4. *Movement of the 6300 A arc across the sky—as observed in the sky (right, h= ∞) and for an assumed height of 300 km (left).*

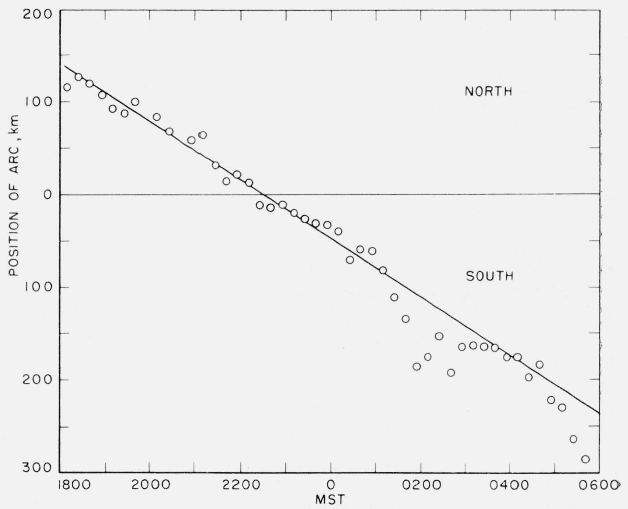

FIGURE 5. *Position of 6300 A arc plotted against time for an assumed height of 300 km.*

4. Tilt of the Arc

In figures 1 and 2 we note that the arc seems to increase in intensity from the zenith to the horizon reminiscent of the so-called van Rhijn effect in the night airglow. This effect reverses during the night, however, as seen in figure 6. The reversal occurs between 2210 and 2225 m.s.t. Referring to figure 7 we note that this is the interval during which the arc crosses the zenith. We thus have the empirical facts that:

(a) When the arc is north of the zenith, it increases in brightness toward the horizon.

(b) When the arc moves south of the zenith, it decreases in brightness toward the horizon.

This combination of facts is consistent with the assumption that the arc is inclined to the vertical along the magnetic lines of force (fig. 8). When the arc is to the north of the zenith, the observer tends to look *across* the arc, which favors a higher intensity toward the horizon. As the arc moves to the south of the zenith, the observer looks more and more *along* the arc favoring a larger effective brightness near the zenith.

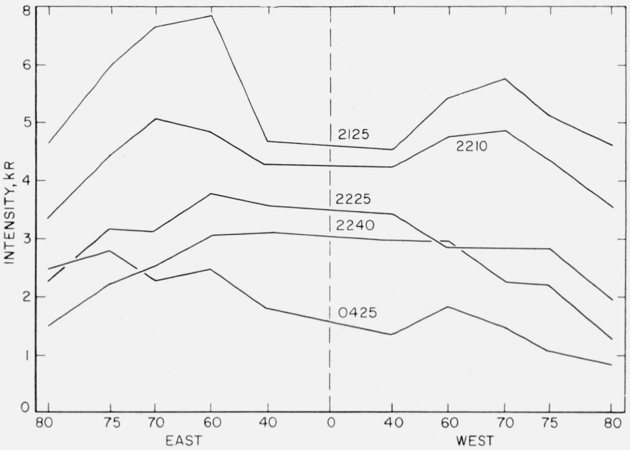

FIGURE 6. *Intensity of 6300 A arc along its length as seen by the observer on the ground at Rapid City for several times during the night of October 22/23, 1958.*

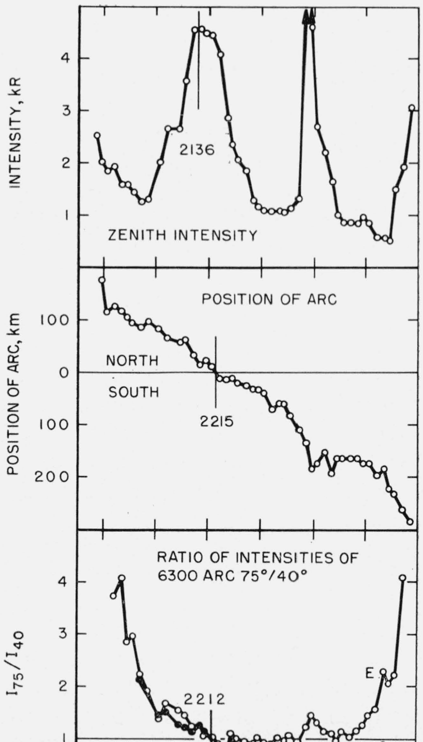

FIGURE 7. *Changes with time of; (a) zenith intensity of 6300 A, (b) position of the 6300 A arc, and, (c) the ratio I_{75}/I_{40}.*

5. Apparent Curvature of the Arc

Figures 1, 2, and 4 all show that our method of plotting results in a curved arc which can be explained by assuming that the arc follows a parallel of latitude (neither geographic nor geomagnetic, as we shall see in the next section). The amount of curvature should, in principle, give a value of the effective height of the arc, but very precise observations would be required to yield a reliable height by this method. A comparison of the observed curvature with that expected for assumed heights of 100, 200, and 300 km indicates that the height is at least 300 km. Throughout this paper, we have assumed an effective height of 300 km.

6. Orientation of the Arc

An inspection of figures 1, 2, and 4 shows clearly that the arc is oriented along the west-northwest to east-southeast direction. This is only *approximately* at right angles to magnetic north. Magnetic north at Rapid City is about 14° east of geographic north; geomagnetic north is 11°.3 east of geographic north. We have estimated on working plots the direction of the perpendicular to each arc and find the following:

Mean of 41 measures__ 22°.9 east of geographic north
Extremes____________ 24°.7 and 20°.2.

Thus, the observed arc is inclined to magnetic parallels by an angle of about 9° and to geomagnetic parallels by an angle of about 12° in the sense that the western part is north and the eastern part south of the parallels.

It is of interest to note that this behavior is similar to that observed for polar auroral arcs. For example, Vegard and Krogness [6] and Vegard [7] found an inclination of 10° for arctic data from the first polar year. Jensen and Currie [8] report a mean inclination of 6° for observations made in Canada. In both cases the sense of the inclination is the same as we have noted in the October 22/23 arc at Rapid City.

7. Southward Movement

The hypothesis might be advanced that the southward movement of the arc during the night is due to the rotation of the observer on the earth's surface under a fixed arc oriented in a west-northwest, east-southeast direction. Calculation shows that a small angle of inclination (between 1° and 2°) is sufficient to account for the observed movement of about 8 m/sec. Since the observed angle is much larger (23°), the hypothesis is not supported.

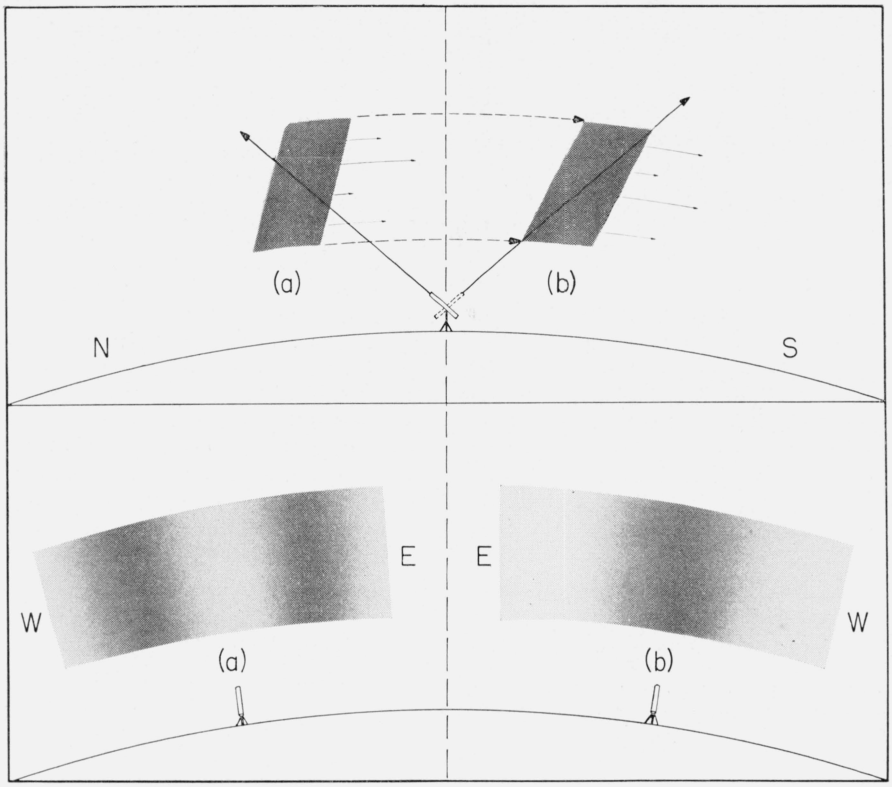

FIGURE 8. *Section (above) and plan (below) views of the arc; (a) to the north of the observer and; (b) to his south.*

The shading in the plan view corresponds to the observed zenith intensity dip when the arc is to the north (a) and the zenith intensity maximum when the arc moves to the south.

8. Discussion

The evidence of this paper, of our earlier study [1], and of the work of Barbier at Haute Provence [2] suggests that there is a family of low latitude auroras with the following characteristics:

(a) The features are "monochromatic" (6300 A present; 5577 A absent). This implies that the excitation mechanism is sufficient to excite the oxygen atom to its ^1D state (2.0 ev) but not to the ^1S state (4.2 ev).

(b) They occur at geomagnetic latitudes as low as 48°. The fact that they have not been observed *overhead* at Haute Provence (Φ=46°) suggests that 48° is actually the lower limit.

(c) They occur as arcs slightly inclined to the perpendicular to the earth's magnetic field.

(d) They may occur concurrently with visible auroras but they seem to be independent of the visible auroral activity both with regard to geographical position and absolute intensity.

(e) 6300 A arcs have been observed in the southern hemisphere at Camden, Australia (Φ=42° S) by Duncan [9]. On September 5, 1958, the apex of such an arc was 74° to the geomagnetic south. If the height is 300 km, the arc would be 820 km or 7°.5 to the south, placing it at a geomagnetic latitude, Φ, of 49°.5.

It is possible that 6300 A arcs are a general feature on the equatorial side of all auroras. If so, they would have escaped general detection since the visual threshold in the red is probably between 6 and 10 kilorayleighs. The two arcs already studied by us had maximum intensities of 6 to 7 kR and were detected only by means of a photometer and not visually. The *color* threshold for 6300 A is probably about 30 kR. We can therefore summarize the nature of the possible observations of such arcs.

Class	Absolute intensity (kR)	Nature of observation
1	1 to 6	Not visible; detectable only with photometers
2	6 to 30	Visible but no color
3	>30	Visible as colored arcs

Most of the historical data on auroral occurrence are based on visual observations, so class 1 arcs (intensity < 6 kR) which might be expected to be the most frequent are just now being studied with monochromatic photometers.

It is possible that class 2 arcs (intensity 6 to 30 kR) may be included in a compilation by Störmer [10]. Many of the features of certain arcs described by Störmer suggest similarities with the arc described in this paper. It is not possible to deduce whether Störmer's arcs were monochromatic (6300 A) or even approximately so. His observations are concentrated over southern Norway at $\Phi=56°$.

The brighter class 3 arcs which appear red (6300 A) to the eye (intensity $>$ 30 kR) seem to be very rare. Störmer [11] records only two such arcs over southern Norway between 1911 and 1940. In a historical review, he lists nine between 1826 and 1872 and concludes "that red arcs very rarely occur, and only during years of great solar activity."

In our earlier paper [1] we suggested the possibility of some relationship between the 6300 A arcs and the newly discovered radiation belts. The arc discussed in the present paper corresponds to a dipole line of force cutting the magnetic equator at a distance of 2.8 earth radii from the center of the earth, just inside the inner edge of the outer radiation belt [12].

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